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The Altitude Dependence of the Local Time Variation of Thermospheric Density

L. R. SHARP, D. R. HICKMAN, C. J. RICE, and J. M. STRAUS
Space Sciences Laboratory
The Ivan A. Getting Laboratories
The Aerospace Corporation
El Segundo, Calif. 90245

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Interim Report

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Dara Batki

Dara Batki, Lt., USAF
Project Officer

Robert W. Lindemuth

Robert W. Lindemuth, Lt Col, USAF
Chief, Technology Plans Division

FOR THE COMMANDER

Leonard E. Baltzell

LEONARD E. BALTZELL, Col, USAF
Asst. Deputy for Advanced
Space Programs

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Analysis of density measurements from the AE-E satellite have demonstrated that the local time variation in the thermosphere at low latitudes ($<20^{\circ}$) changes from predominantly diurnal at high altitudes ($\sim$300 km) to predominantly semi-diurnal at low altitudes ($\sim$140 km). This behavior is significant because it both affects the accuracy of density predictions at low satellite altitudes and confirms that the mesospheric semidiurnal tide is important to the dynamics of the lower thermosphere. Comparison of the results with the local time dependence found in the thermospheric model of Jacchia (1971) and the MSIS model of Hedin et al.

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(1977 a and b) indicate that only the latter correctly models the transition to dominantly semidiurnal behavior at lower thermospheric altitudes near the equator.

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FIGURES

Introduction

Data obtained from high altitude satellites have shown that the atmospheric density has a strong diurnal variation, maximizing near the subsolar point at around 14 LST. For the most part, atmospheric models which have been based principally on data gathered above about 250 km, where the diurnal character is very pronounced, have extrapolated this behavior to lower altitudes though with decreasing amplitude. Some indication that such a straightforward extrapolation may not be correct has been given by the San Marco 3 satellite data presented by Newton et al. (1975). These investigators found at 220 km two distinct peaks of equal amplitude at 11 LST and 18.5 LST. Newton et al. attributed this behavior to the different phase in the diurnal response of individual constituents O and N_2. That the number density of each atmospheric constituent peaks at a different time of day has also been deducted by Mayr et al. (1974) from analysis of OGO-6 mass spectrometer data.

We have used density data from a cold cathode gauge on board the equatorial satellite Atmosphere Explorer E to investigate the diurnal behavior of the atmosphere from 300 km down to 140 km. The data are used to determine the phase and relative amplitude of the diurnal and semidiurnal components of the local time variation as a function of altitude. These parameters are valuable as an indication of the relative magnitude of energy sources for the lower thermosphere since a diurnal component may be expected to result from local heating while the semidiurnal component would be driven by tides propagating upwards from the stratosphere and mesosphere (Lindzen, 1976). Assignment of a

source would also depend, of course, on such details as phase and phase progression and the altitude-dependence of the wave amplitude.

Discussion

The data used in this study consist of 5062 density measurements obtained using the cold cathode ion gauge known as Pressure Sensor A (PSA) on board the Atmosphere Explorer E (AE-E) satellite. The instrument has been described by Rice et al. (1973), and the data reduction procedure has been presented by Rice and Sharp (1977). AE-E is in a near-equatorial orbit, with an inclination of 19.6°. The data used in this study were gathered between December 1975 and October 1976 when AE-E was in an eccentric orbit (140 km × 2757 km). The data set was further limited by including only data obtained during periods of oriented (non-spinning) operation. Density and ephemeris data at fixed altitude levels at 5 km intervals (140-300 km) were tabulated for use in the present study. In order to minimize the complicating and incompletely modeled effects of geomagnetic activity, the data base excludes any data for which $Kp \geq 5$ at any time during the period six hours prior to the time of measurement.

In order to isolate the local time variation in the lower thermosphere, all the other known contributions to the variability of the density were suppressed using the Jacchia (1971) model, evaluated using all appropriate input parameters, but with the local time set arbitrarily at midnight. The ratio R of the measured density to this model value was then averaged over each two-hour interval of local time. The results of this analysis are shown in Figure 1. Each curve represents the average of this ratio over the five altitude levels in a 20 km band centered at the designated altitude. (For example, the 290 km

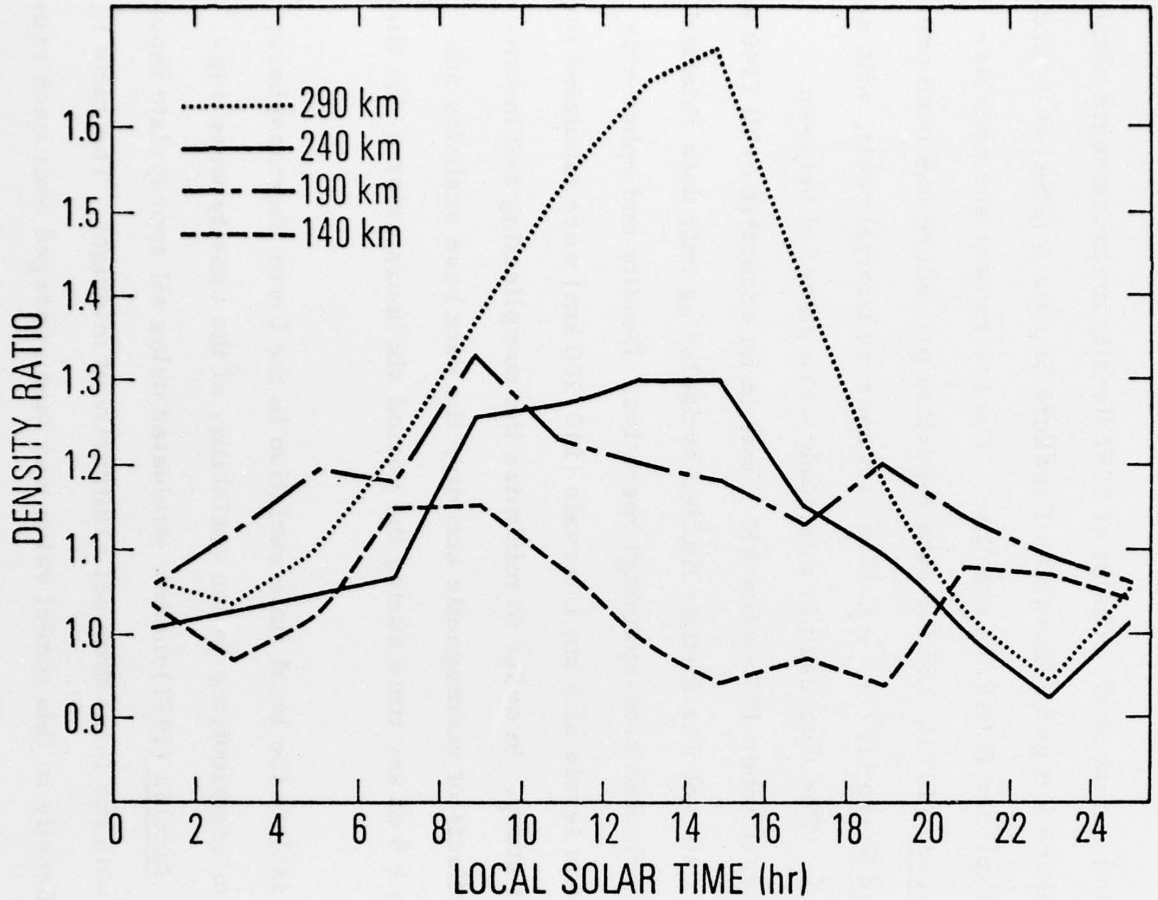

Fig. 1. Average ratio of the measured density to the Jacchia (1971) model prediction as a function of local solar time. The local time parameter for the model is taken to be local midnight in all cases, but all parameters are handled in the manner prescribed in the model formulation. The data are binned at two-hour intervals. Each curve includes all altitude increments within the 20 km band centered on the designated altitude.

curve includes data from the 280-300 km range.) The curves thus represent the qualitative altitude dependence of the local time variation which occurs near the equator. There is a systematic transition from the clearly diurnal behavior at 290 km with a well-defined maximum near 14 hours local time and a broader minimum near midnight to the semidiurnal behavior at 140 km. In the transition region between these altitudes the daily variation is somewhat less well-defined due to the fact that neither the diurnal nor the semidiurnal mode is clearly dominant.

In order to study the altitude dependence of the daily density variation in greater detail, we have performed a two-component harmonic analysis of the ratio R after dividing by the mean value. The amplitude and phase of the diurnal and semidiurnal terms were calculated for each 5 km altitude step in the 140-300 km data base. Initially a three-component fit was made, but the terdiurnal component showed no phase continuity with altitude, and the amplitude at all points was too small to be statistically significant. Furthermore, neglect of the third harmonic in later analyses did not significantly affect either the amplitude or phase of the resultant diurnal and semidiurnal terms. A somewhat similar analysis using data from the San Marco 3 satellite at higher altitudes has been described by Broglio et al. (1976).

In Figures 2 and 3 we present the amplitude and phase, respectively, determined in each of these decompositions. The amplitudes and phases of the two modes are shown as functions of altitude, along with the corresponding predictions of two widely used empirical models of the thermosphere, the Jacchia (1971) model and the Mass Spectrometer-Incoherent Scatter (MSIS)

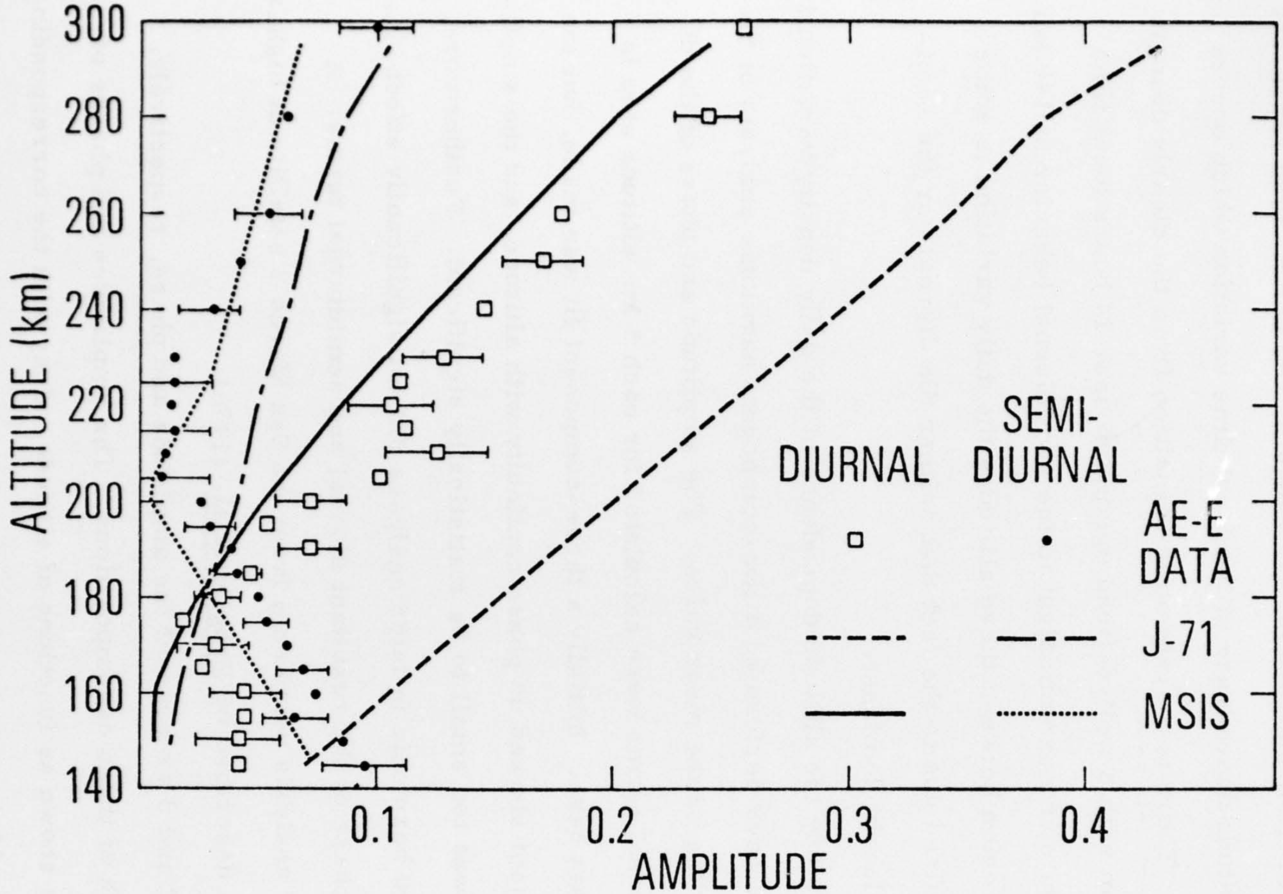

Fig. 2. Amplitude of the diurnal and semidiurnal components of the local-time variation for the AE-E data base resulting from a two component harmonic decomposition. The error bars present a statistical measure of the goodness of fit at each altitude; for clarity they are only given every other altitude increment. Also plotted are the results of performing a similar decomposition on the density values calculated by means of the Jacchia (1971) and MSIS thermospheric models.

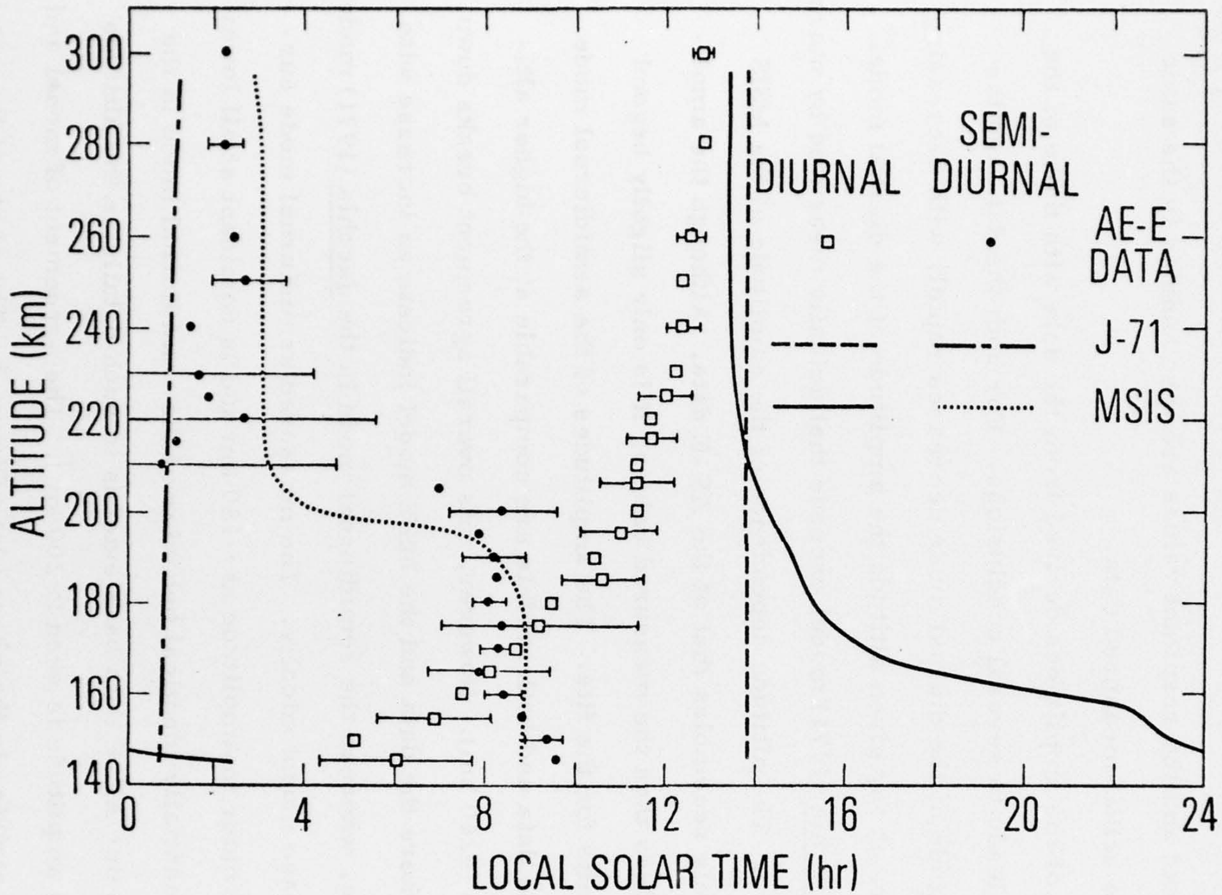

Fig. 3. Phase of the diurnal and semidiurnal components of the local-time variation corresponding to the amplitudes in Fig. 2.

model of Hedin et al. (1977). In calculating the amplitude and phase predictions of the empirical models, model densities are determined for every point in our AE-E data set and the resultant values are then handled in the same manner as with the actual measured data.

Comparison of the amplitudes derived from the data with those of the empirical models leads to several conclusions. For both the data and the models, the amplitude of the diurnal mode decreases rapidly with decreasing altitude. However, at any given altitude the amplitude of the diurnal model predicted by the Jacchia (1971) model exceeds that actually measured by more than a factor of two. The altitude dependence of the amplitude of the MSIS diurnal mode closely resembles that of the AE-E data. Although the amplitude is uniformly less than the measured values, it is only slightly beyond the uncertainty limits for the fits. The amplitudes of the semidiurnal mode calculated from the data and both models are comparable at the higher altitudes treated here (≥240 km). However, this overall agreement breaks down below ~200 km, where the data and the MSIS model indicate an increase with decreasing altitude, whereas the semidiurnal mode in the Jacchia (1971) model continues to decrease monotonically. The measured semidiurnal mode surpasses the diurnal mode in amplitude at ~180 km and is dominant at all lower altitudes. The essentially identical behavior of the semidiurnal mode in the MSIS model and in our AE-E data base extends to such details as the altitude at which minimum amplitude is seen (~200 km). The agreement of model and data is even more striking in the phase plot, Figure 3. The phase of the semidiurnal mode, which at high altitudes is almost constant between 2 and 3 hours

LST, makes near 200 km a nearly discontinuous transition to a phase angle between 8 and 10 hours LST. The Jacchia (1971) model extrapolates the behavior at higher altitudes downward to the lower thermosphere as well.

The measured phase of the diurnal mode shows good agreement with the models at high altitudes, but considerable disagreement at low altitudes. The phase in the measured data progresses from near 13 hours LST at 300 km toward earlier times, reaching 6 hours LST at 140 km. The phase of the MSIS model, on the other hand, though starting at a similar point at high altitude, progresses toward later times, reaching 2.5 hours LST at 140 km. The Jacchia (1971) model shows a diurnal phase which remains constant at 14 hours LST. This divergence can probably be attributed to the manner in which the data used in constructing the models was obtained. The data base for the Jacchia (1971) model contained no data below an altitude of ~ 260 km; the constant phase results from extrapolating downwards the behavior of the upper thermosphere and, hence, good agreement in the lower thermosphere might not be expected. On the other hand, the low altitude data input to the MSIS model is almost exclusively from the Atmosphere Explorer C satellite. We believe that the behavior of the phase of the diurnal mode in the MSIS model may be an artifact arising from the strong coupling in the AE-C data base of local time with other parameters such as latitude and season. Because the amplitude of the diurnal mode is small at low thermospheric altitudes, such behavior has little effect on the density there. To test this hypothesis we performed the above analysis using our own ion gauge data from the AE-C

satellite and obtained results which were qualitatively similar to the MSIS predictions with respect to the diurnal phase progression at low altitude.

The MSIS model semidiurnal mode agrees quite well in phase with the data showing the sharp phase transition associated with the change from EUV to tidal domination below ~ 200 km. The Jacchia (1971) model fails to reproduce this behavior and disagrees substantially in phase at the lower altitudes studied here. This suggests that the MSIS model is more reliable for studies involving lower thermospheric chemistry and dynamics than is the Jacchia (1971) model. In this connection it should be noted that the MSIS model exhibits the semidiurnal mode as dominant only at low latitude; at 140 km the diurnal mode is dominant above about 30° latitude. Our data from AE-E cannot confirm or deny this behavior, however.

The general behavior of a dominant diurnal mode at high altitudes and semidiurnal mode at low altitudes is consistent with the following picture. At high altitudes the characteristics of thermosphere are determined largely by the day-night variations in EUV heating, leading to a diurnal variation whose amplitude decreases with decreasing altitude because the heating rate per unit mass decreases with decreasing altitude. The behavior at low thermosphere altitudes arises from the propagation of tidal waves from lower regions of the atmosphere. These tides are known to be predominantly semidiurnal in character (Lindzen et al. 1976; Wand, 1976) and their amplitudes decrease with increasing altitude in the thermosphere.

Although comparison of phase in density data with that in temperature must be approached with a good deal of caution, it is worth pointing out the

qualitative similarity of the altitude dependence of the density phase measurements reported here and the temperature phase calculated for the solar semidiurnal tide by Lindzen and Hong (1974) for equinoctial conditions near the equator, including the nearly 180° phase change seen near 200 km and the more gradual shift toward later local time evident below 160 km. The calculations of temperature phase by Lindzen and Hong (their Figure 20) show this behavior uniformly 40-50 km below the altitudes at which it is seen in our density measurements. On the other hand, the calculations for solstitial conditions show much more extreme phase changes with altitude (720° over the same altitude band, 125-175 km), and since our data base encompasses solstitial and equinoctial conditions approximately equally, the previous noted qualitative agreement may be only fortuitous. Given the general character of the altitude dependence of the semidiurnal mode, it seems to us reasonable to ascribe this behavior to the solar semidiurnal tide. With this interpretation, the transition between the part of the thermosphere dominated by tides and the EUV-dominated upper thermosphere occurs near the equator in the 200-220 km altitude range.

Conclusion

The Atmosphere Explorer E density data suggest that the upward propagating mesospheric tidal wave dominates the local time behavior near the equator in the lower thermosphere up to about 180 km and is important to at least 200 km. Thus the common assumption of a predominantly diurnal density variation below $\sim$200 km may lead to serious errors in density predictions and cause errors in any calculation attempting to determine the dynamical behavior of the atmosphere below 200 km. Of those atmospheric models known to us, only the MSIS model of Hedin et al. (1977) reproduces the measured data.

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References

Broglio, L, C. Arduini, C. Buongiorno, U. Ponzi and G. Ravelli, San Marco 3 drag balance results below 320 km altitude in the equatorial atmosphere, Space Research XVI, Akademie-Verlag, Berlin, 1976.

Hedin, A. E., J. E. Salah, J. V. Evans, C. A. Reber, G. P. Newton, N. W. Spencer, D. C. Kayser, D. Alcaydé, P. Bauer, L. Cogger and J. P. McClure, A global thermospheric model based on mass spectrometer and incoherent scatter data MSIS 1. N_2 density and temperature, J. Geophys. Res., 82, 2139, 1977a.

Hedin, A. E., C. A. Reber, G. P. Newton, N. W. Spencer, H. C. Brinton, H. G. Mayr and W. E. Potter, A global thermospheric model based on mass spectrometer and incoherent scatter data MSIS 2. composition, J. Geophys. Res., 82, 2148, 1977b.

Jacchia, L. G., Revised static models of the thermosphere and exosphere with empirical temperature profiles, Smithsonian Astrophys. Obs. Spec. Rep. No. 332, 1971.

Lindzen, R. S., A model decomposition of the semidiurnal tide in the lower thermosphere, J. Geophys. Res., 81, 2923, 1976.

Lindzen, R. S. and S.-S. Hong, Effects of mean winds and horizontal temperature gradients on solar and lunar semidiurnal tides in the atmosphere, J. Atmos. Sci., 31, 1421, 1974.

PRECEDING PAGE BLANK-NOT FILMED

Mayr, H. G., A. E. Hedin, C. A. Reber and G. R. Carignan, Global characteristic in the diurnal variations of thermospheric temperature and composition, J. Geophys. Res., 79, 619, 1974.

Newton, G. P., W. T. Kasprzak, S. A. Curtis and D. J. Pelz, Local time variation of equatorial thermospheric composition determined by the San Marco 3 Nace, J. Geophys. Res., 80, 2289, 1975.

Rice, C. J., V. L. Carter, S. R. LaValle, W. T. Chater, D. A. Jones, C. G. King and D. F. Nelson, Atmosphere explorer pressure measurements: ion gauge and capacitance manometer, Radio Sci., 8, 305, 1973.

Rice, C. J. and L. R. Sharp, Neutral atmospheric waves in the thermosphere and tropospheric weather systems, Geophys. Res. Let., 4, 315, 1977.

Wand, R. H., Semidiurnal tide in the E region from incoherent scatter measurements at Arecibo, Radio Sci., 11, 641, 1976.

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El Segundo, California

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